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A Study on the Design of Feedback Adaptive Controller

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Abstract

In this paper, we propose a feedback adaptive controller which need not adjustment of the scale factor. Numerical examples are included to illustrate the procedure of a adaptive control and to show the performance of the control system.

We can observe that the output of control system.converges toward the reference of response.

Keywords : Adaptive, Feedback, PID, MRAC, STC

I Introduction

An adaptive control is an important area of modern control, dealing the control of systems in the presence of uncertainties, structural perturbations, and environmental variation. An adaptive control was first proposed by Draper and Li as far back as 1951. There are two principal approach methods to an adaptive control - model reference adaptive control(MRAC), and STR(self-tuning regulator).

The original idea of self-tuning was first given by Kalman in 1958. self-tuning regulator represent an important class of an adaptive controllers; they are easy to implement and are applicable to complex processes with the variation of characteristics involving unknown parameters, the presence of time delay, time-varying dynamics process, and stochastic disturbances. In MRAC, the basic idea is to asymptotically drive the output of an unknown plant in structure of a reference model, the basic procedure in self-tuning is to select a method of design for known plant parameters and the unknown plant using recursively estimated values of these parameters[1].

In PID controller, the output of the plant must be arrived in the desired value by adjustment of PID coefficients, but, the change of the reference value must adjust again the gains of PID controller.

Optimal control demands the solution of Riccati equation. In an adaptive control, MRAC demand the reference model and self-tuning regulator demands the identity of the order of plant and a classes of plant[1][2].

A Fuzzy control is tuning the scale factor of fuzzifier as a classes of plant by the error and the change rate of error when defuzzifying[3]. Neural Network must modify many parameter when it is learning[4].

As above, a controller have the problem of tuning to adjust parameters when the algorithm applied a plant.

In this paper, We propose the control algorithm that need not the adjustment of parameter when it's tuning.

II. The design of feedback adaptive controller

The structure of the proposed controller is configured basically by the general feedback control. The general feedback controller is operated that supply to the plant making the control input multiplying the appropriate gain of controller by the error between the output of the plant and the reference. In this point, the optimal selection method of the appropriate control gain is as follows.

First, we generate the expected control input using the desired reference of the past and the relation between the past input of the plant and the present output of the plant.

Second, we must generate the appropriate control gain which needs for the next stage using the estimated control input and the error between the desired reference of the past and the present output of the plant.

1). The design of a feedback controller

A block diagram of the feedback controller for feedback adaptive controller shown in Fig. 1.

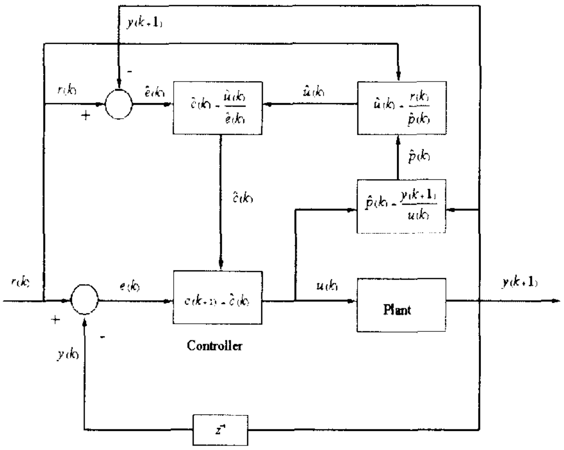

Fig. 1. Block diagram representation of feedback controller

<Inference procedure of a feedback controller>

① Given control input $u(k) = \varepsilon$ in control system.

② A structure of control system $\hat{p}(k)$ infer from it's k-th control input $u(k)$ and output $y(k+1)$.

$$\hat{p}(k) = \frac{y(k+1)}{u(k)} \tag{1}$$

③ An estimated control variable $\hat{u}(k)$ infer from structure of control system $\hat{p}(k)$ and reference $r(k)$.

$$\hat{u}(k) = \frac{r(k)}{\hat{p}(k)} \tag{2}$$

④ An error $\hat{e}(k)$ calculate from k-th reference $r(k)$ and output $y(k+1)$.

$$\hat{e}(k) = r(k) - y(k+1) \tag{3}$$

⑤ A gain of feedback controller $\hat{c}(k)$ calculate from error $\hat{e}(k)$ and estimated control variable $\hat{u}(k)$. .

$$\hat{c}(k) = \frac{\hat{u}(k)}{\hat{e}(k)} \tag{4}$$

⑥ $c(k+1)$ replace $\hat{c}(k)$.

$$c(k+1) = \hat{c}(k) \tag{5}$$

We show in Fig.2 that a response applied at linear plant of equation(6) and equation(7a) using the control algorithm represent in Fig.1.

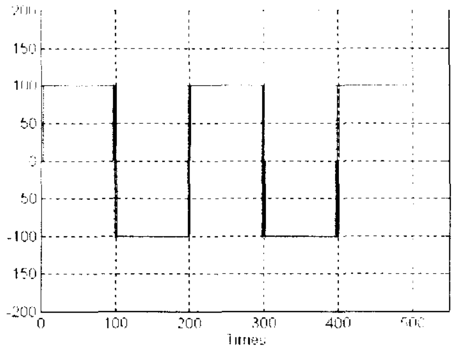

Fig. 2. Output and input of the result applying the feedback control algorithm to plant of equation (6)

$$y(k+1) = au(k), \quad a = 10 \tag{6}$$

We can observe that they agree with the reference from consequence of Fig. 2. and Fig. 3.

Given a continuous-time control system with the transfer function as follow

$$G(s) = \frac{1.2033\times10^{8}}{s^2 + 2.9627\times10^{3} + 6.5775\times10^{6}} \tag{7a}$$

Equation (7b) is output of discret-time control system with a sampling time of T=0.2ms.

$$y(k+1) = 1.39711y(k) - 0.538894y(k-1) + 2.59383u(k) \tag{7b}$$

Let's continuous-time control system with the transfer function as follow

$$G(s) = \frac{0.15e^{-0.45s}}{s+0.15} \tag{8a}$$

The discrete-time control system with a sampling time of T=1ms follow that

$$y(k+1) = 0.8607y(k) + 0.0792u(k) + 0.0601u(k-1) \tag{8b}$$

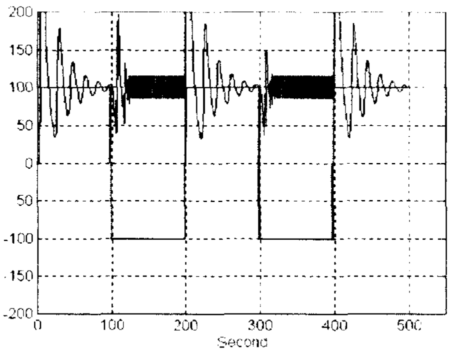

Fig. 3. Output and input of the results applying the feedback control algorithm to plant of equation (7)

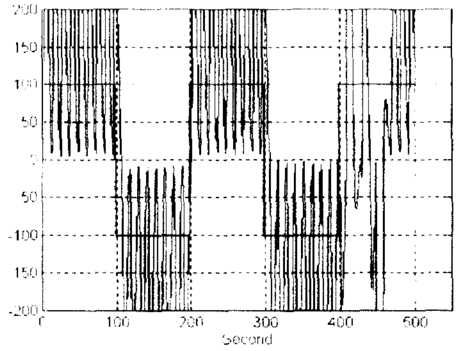

Fig. 4. Output and input of the results applying the feedback control algorithm to plant of equation (8)

We can observe unstable a oscillation compare the reference with a response of Fig. 3. and Fig. 4.

We think that this problems will be solved if apply to the feedback control algorithm by estimate the structure of plant to get optimal gain of feedback controller.

2). Design of a feedback adaptive controller

We can solve the defect of proposed algorithm in Fig1 through an adaptive control method.

This feedback adaptive controller can consist of three loops. The inner loop consists of plant and an ordinary feedback controller. The parameters of controller are adjusted by the outer loops, which is composed of a recursive least squares estimator.

Inference procedure of feedback controller $p(k)$ at step (2) infers through recursive parameter estimator.

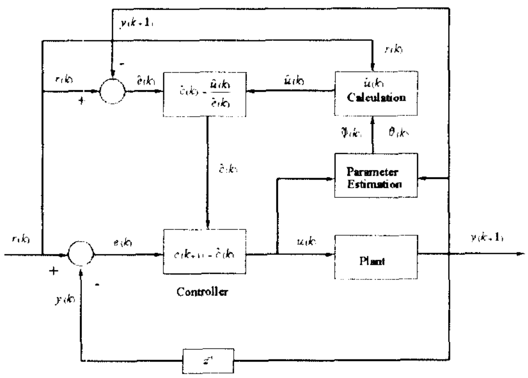

Fig. 5. Block diagram of the propose feedback adaptive controller

Recursive parameter estimator is an important part of a feedback adaptive controller[5][6]. There are many different methods which could be used for parameter estimation. For example stochastic approximation, least squares, extended least squares, generalized least squares, multistage least squares, instrumental variables, and maximum likelihood. Unfortunately, there is no the best method to recursive parameter estimator, there are many different possibilities. For simplicity we use a recursive least squares estimation in this paper. Least squares is one of the simplest recursive estimation procedures.

Consider a plant characterized by

$$Ay(k) = Bu(k) \tag{9}$$

where A and B are polynomials in the forward shift operator. It is assumed that A and B are co-prime and that

$$\deg B < \deg A \tag{10}$$

where deg A, B denotes the degree of the polynomial In the criterion of recursive squares estimation

$$V = \sum_{k=1}^{t} \lambda^{t-k} \varepsilon^2(k) \tag{11}$$

where

$$\varepsilon(k+\deg A) = Ay(k) - Bu(k) \tag{12}$$

we must be minimized. Weight factor λ is used for a decrease the weight toward old parameter. To describe algorithm of the model, equation(9) is a written explicitly as

$$y(k+1) + a_1 y(k) + a_2 y(k-1) + \cdots + a_n y(k-n) = b_0 u(k) + b_1 u(k-1) + \cdots + b_m u(k-m) \tag{13}$$

Introduce a vector of parameter estimates

$$\theta = [\widehat{a_1}\ \widehat{a_2} \cdots \widehat{a_n}\ \widehat{b_0}\ \widehat{b_1} \cdots \widehat{b_m}] \tag{14}$$

and a vector of regressors

$$\phi(k) = [-y(k)\ \ -y(k-1) \cdots -y(k-n)\ \ u(k)\ u(k-1) \cdots u(k-m)]^T \tag{15}$$

then, the recursive least squares estimate is given by

$$\theta(k+1) = \theta(k) + P(k+1)\phi(k+1)\varepsilon(k+1) \tag{16}$$

where

$$\varepsilon(k+1) = y(k+1) - \theta^T(k)\phi(k+1) \tag{17}$$

and

$$P(k+1) = [P(k) - P(k)\phi(k)R(k)\phi^T(k)P(k)]/\lambda \tag{18}$$

where

$$R(k) = [\lambda + \phi^T(k)P(k)\phi(k)]^{-1} \tag{19}$$

Parameter estimate vector θ and regressors vector $\phi(k)$ obtained through recursive least squares estimate was modified as follows.

$$\hat{\theta} = [\widehat{a_1}\ \widehat{a_2} \cdots \widehat{a_n}\ \ \widehat{b_1}\ \widehat{b_2} \cdots \widehat{b_m}] \tag{20}$$

$$\hat{\phi}(k+1) = [-y(k+1)\ \ -y(k) - y(k-1) \cdots -y(k-n)\ u(k-1) \cdots u(k-m)]^T \tag{21}$$

Calculate the estimated control variable $\hat{u}(k)$

$$\hat{u}(k) = \frac{r(k) - \hat{\theta}^T(k)\hat{\phi}(k+1)}{b_0} \tag{22}$$

This method of parameter estimation is called the recursive least squares with exponential forgetting[5][6].

In Fig. 6 and Fig. 7, we shown a result applying proposed feedback adaptive control algorithm in plant of equation(7), (8) adding white noise with zero mean value and variance 1.

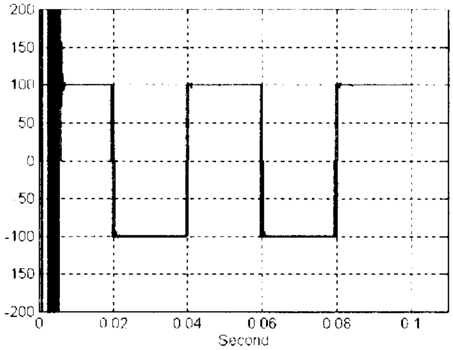

Fig. 6. Comparison of output and input for the results applied feedback adaptive control algorithm to system of equation (7)

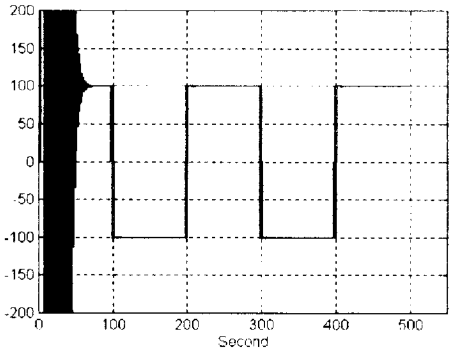

Fig. 7. Comparison of output and input for the results applied feedback adaptive control algorithm to system of equation (8)

III. Conclusions

We can observe that the output of control system converges toward the reference of Fig. 6. and Fig. 7 very well and this algorithm could be used easily. Also, the behaviour of feedback adaptive system is very good from the second transient.

In this paper, We proposed the feedback adaptive control which need not adjustment of the scale factor, but they have a defect that we must know the order of the plant.

Therefore, for solve this problems in the future, we must introduce fuzzy or neural theory and must expand the case of known plant or nonlinear plant.

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